

Ecological Survey Recommendations for the Buffalo National River and Ozark National Scenic Riverways Parks

Prepared by



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Introduction

On 13 and 14 July 2004, the National Park Service (NPS) convened a workshop of biologists, statisticians, and administrators to discuss ecological monitoring of the Buffalo National River (BUFF) and Ozark National Scenic Riverways (OZAR). The purpose of this workshop was to identify elements of a spatial and temporal survey design targeting multiple ecological resources within the two river ecosystems. Following background presentations on the Ozark hellbender, heavy metals, fish communities, macroinvertebrates, and geomorphology of the parks, break out sessions developed recommendations for a spatial design that met the particular objectives and logistical constraints of each project. Reconvened, the workshop identified common themes among the spatial survey recommendations, and discussed temporal survey designs for each of the five target resources. The group then finalized recommendations for characteristics of the spatial and temporal design elements and discussed potential co-location and co-visitation of sample points across projects.

This document contains both a summary of those final design recommendations and additional recommendations necessary to implement a unified survey in the two subject parks. Recommendations are given for definition of a common sample unit, construction of the sampling frame, selection of units from the sampling frame, and the schedule of visits to units selected in the sample. Co-location and co-visitation are also discussed and an alternate allocation of sample units to temporal revisit schedule is proposed that maximizes co-location and co-visitation for studies with common revisit schemes. Because this document focuses on the statistical aspects of a planned monitoring study, certain important topics are not present here. In particular, biological and managerial motivation for monitoring the proposed species, specific study objectives, and field protocols are not presented.

At the workshop, 5 separate studies were discussed; the hellbender, heavy metals, fish communities, macroinvertebrates, and geomorphology. After initial discussion, it was apparent that the heavy metals study was actually composed of two separate studies. One heavy metal study was designed to monitor bio-available lead in the parks, and commercial mining of lead nearby was a primary concern. The other heavy metal study targeted monitoring of mercury levels in fishes, primarily small mouth bass, of the parks. It became clear that the mercury study required small mouth bass specimens for analysis, and that it would be efficient to combine specimen collection efforts of the mercury and fisheries studies. That is, it would be extremely efficient for the mercury study to analyze small mouth bass captured by the fish project. This document, therefore, has combined the mercury and fish projects for survey design purposes. If the mercury project requires more small mouth bass than the fisheries project will collect, the mercury and fisheries projects should again be viewed as separate studies for survey design purposes. In this case, the general recommendations and sampling philosophy contained herein will still apply, but additional recommendations regarding the membership and revisit plan of the mercury study will be necessary. After combination of the fish and mercury study's collection efforts, the following 5 studies are planned for BUFF and OZAR: hellbender, fish + mercury, geomorphology, macroinvertebrates, and lead.

Definition of Common Sample Units: River Stretches

In general, *sample units* are defined to be the smallest entities upon which a particular field protocol will be applied. For example, if a particular field protocol (such as water sample collection and dissolved oxygen analysis) could be applied in a single pool of a river, the sample unit would be a pool. If a field protocol (such as snorkel surveys for fish abundance) requires a set of consecutive pools in a river, the sample units would be a set of consecutive pools. Often, the definition of a sample unit is dependent upon definition of a lower-level entity, such as the definition of a pool, riffle, or run.

When designing a unified monitoring survey that encompasses multiple species and field protocols, it can be difficult to arrive at a suitable common sample unit definition because each study requires different entities for response measurement. In this case, however, it was possible to define the sample unit to be the largest entity upon which one of the 5 study's field protocols could be applied. In most cases, individual studies with separate field protocols will need or want to sub-sample the sample unit in order to efficiently obtain a single measurement for the unit. For example, if sample units are defined to be stretches of river that contain many pools, the water collection protocol might specify gathering water samples from a randomly selected sample of 3 pools in the stretch. In this case when multiple field protocols can utilize the same fundamental field unit, the definition of *sample unit* should be changed to "entities selected during a random draw of the sampling mechanism", rather than the smallest entities upon which measurements are made.

At the survey design workshop for BUFF and OZAR, the agreed-to common sample unit definition was a *stretch* of contiguous river with a recommended minimum and maximum length. To accommodate the five proposed monitoring studies, the minimum and maximum length of sample units will vary in different parts of the river system. In tributaries and the upper mainstem of both rivers, sample units from 1 km to 3 km may be adequate. The middle and lower mainstem stretches may require stretches from 3 km to 5 km in length in order to accommodate all studies. These minimum and maximum stretch lengths are estimates. A key characteristic of the overall design is that all studies are capable of producing unbiased estimates that are applicable to the entire stretch. While stretches need to be large enough to accommodate unbiased estimates from all studies, stretches do not have to be the same size, nor do they have to strictly conform to a prescribed minimum and maximum length.

For efficiency in locating sample units in the field, it is recommended that, whenever possible, the lower and upper boundaries of units be fixed at obvious permanent landmarks such as bridges, assess points, confluences, rock cliffs, canyons, valley segment type boundary, etc. Due to perceived differences in certain responses near the confluences of tributaries and main stem rivers, it was recommended that the mixing zone below confluences and the backwater zone at the bottom of tributaries be included in the same stretch (Figure 1). If desired, this method of stretch construction will allow post-stratification of study units into one of three categories labeled "mainstem", "tributary", and "confluence". Post-stratification will allow estimates to be made separately for each stratum. With the understanding that the length, boundary, and confluence recommendations take precedence, sample units should be as uniform in length as possible. Once defined, sample unit boundaries are designed to remain fixed forever and to be used by all studies under the unified monitoring design.

The primary alternative to defining sample units as stretches of river is to define sample units as points along the river. Although valid statistically and workable in a number of monitoring situations, defining sample units as points causes additional complications in several areas. Defining sample units as points requires separate definitions of support reaches required by each study's field protocol. Additional protocols with undesirable consequences are required for points near the ends of each river and tributary. Analysis of point-based samples is much more complicated in most cases than analysis of positive-area sample units contained in finite populations.

Sample Frame

The *sample frame* (or just *frame*) is defined to be a finite list of sample units, each of which is theoretically measurable by at least one study's field protocol. Statistical inferences are not possible to sample units that are not included in the frame, and in this way the frame defines the totality of area to which statistical inferences are possible (i.e., the *area of inference*). The totality of areas to which inferences are desired is called the *population*. It is hoped that the sample frame is an accurate representation of the population, but due to errors of omission and inclusion, the sample frame usually does not represent the desired population perfectly.

Separate sample frames were recommended for BUFF and OZAR to accommodate separate estimates of resources in each park. For both parks, the sample frame should consist of all river stretches where it is theoretically possible to apply at least one study's field protocol. The initial sample frame of stretches is to be constructed from blue lines on 1:24,000 USGS digital line graphs (DLGs), and subsequently updated following reconnaissance surveys (see Reconnaissance Surveys). If it is possible for at least one study to apply its protocol in a particular stretch, but other field protocols cannot be applied, the stretch should still be included in the frame. The fact that less than the full suite of field protocols can be applied to a stretch will be accommodated by excluding stretches where a particular protocol cannot be applied. This method, which involves defacto separate sample frames, creates areas of inference that differ among studies. The possibility of different areas of inference was not deemed great because the 5 study protocols envisioned for BUFF and OZAR could, in theory, be applied to all sections of the targeted rivers.

There are, however, two known restrictions on the area of inference represented by the frame. One restriction is structural in nature, while the other will occur more-or-less at random. Because hellbenders are only known to occur in main stem stretches of both parks, the hellbender study structurally restricted their area of inference to main stem stretches by choosing to sample only those stretches. Effectively, the hellbender sampling frame will only contain main stem stretches. The contaminants study chose to analyze small mouth bass for mercury levels, and to rely upon the fish study to capture their bass specimens. If no small mouth bass are captured in a stretch, the mercury study will report a missing value as their response on that stretch. This situation imposes an (as yet) unknown spatial restriction on the area of inference for the contaminants study because a mercury level cannot be inferred to stretches without small mouth bass. Both of these restrictions are acceptable in the sense that statistically valid estimates can be constructed for the area of inference from data collected by the design.

It was deemed desirable at the workshop to attribute each stretch in both frames with the following characteristics which will be used as covariates: (1) whether or not the stretch is significantly influenced by the presence of a major spring, (2) whether or not the stretch was defined to be a tributary, main stem, or confluence stretch, (3) the valley segment type of the stretch, and (4) whether or not the stretch was ephemeral (i.e., subject to intermittent flow). Other attributes are possible and should be considered. Some of these attributes are matters of professional opinion and are best constructed after a suitable reconnaissance survey has been conducted. Unless it is absolutely necessary for a particular study to visit one or more stretches with a particular rare attribute, none of these attributes will be used to define sample strata for a particular study. Rather, these attributes will be used during analysis to help explain variation in the measured variables. Attribute (2) will be used to select main stem stretches for visitation by the hellbender study.

Reconnaissance Surveys

While construction of the sample frame is largely a GIS exercise, attaching attributes, verifying accuracy, and verifying access can and should involve a minimal amount of field work. At the design workshop, a low-effort reconnaissance survey was recommended to assist attachment of attributes to sample units and to verify accuracy of the frame. After initial sample frame construction, envisioned reconnaissance surveys involved floating by raft or canoe all stretches. If, given funding and logistical constraints, it is not possible to float all stretches in the initial frame, only those on main stem rivers would be visited. During reconnaissance only attributes and data that could be collected without stopping the crew's boat would be recorded. Non-floatable stretches would be walked if time, personnel, and budget allowed. If key attributes and locations are known with high confidence for certain stretches, it would not be necessary to visit them during reconnaissance surveys.

Following reconnaissance surveys, attributes of stretches in the initial frame would be updated, and any known errors in the DLGs would be corrected. Stretches could be eliminated, amalgamated, or added to the initial frame during this step. Stretch boundaries would also be updated if prominent permanent features were noted during the reconnaissance visit. It was noted that initial frame construction, reconnaissance surveys, and finalization of the sample frame could require 1 field season to complete.

Sample Selection

A *sample* is defined as a subset of units in the frame that has been selected by some random mechanism with known properties. For example, a simple random sample without replacement selects one unit from the frame at random, selects another unit from the remaining units at random, selects a third unit from the remaining units at random, and so on. A systematic sample of units selects a random starting unit among the first 10, say, in an ordered frame (e.g., the 7th), and then includes every 10th unit thereafter (i.e., the 17th, 27th, 37th, etc.).

For all studies involved in the BUFF and OZAR monitoring projects, it was deemed desirable for the sample to be *spatially balanced*. A sample with good spatial balance is loosely defined as a sample that is “well spread-out”. A sample that is “well spread-out” does not contain large numbers of units that are close together in space, and that does not produce large areas without sampled stretches. In river systems, “space” is 1-dimensional and equates to river mile. Spatial

balance was deemed important because all responses were known to be spatially autocorrelated (i.e., units “close” to one another tend to yield correlated responses), and park-wide inferences were desired. When responses are correlated in space, spatial balance can greatly improve precision of the resulting estimates. Given these considerations, and the importance of commonly sampled stretches, spatial balance was favored over sampling that targeted certain areas where responses were deemed uniform or “representative”.

At the design workshop, three spatial sampling plans were considered for application to BUFF and OZAR. The sampling plans considered at the workshop were simple random sampling, systematic sampling, and generalized random tessellation stratified (GRTS) sampling. Simple random sampling, which selects stretches from the frame completely at random, was considered but quickly abandoned because the scheme does not guarantee spatial balance. Systematic sampling, which requires that the frame be spatially ordered and that every k^{th} stretch after a random start be selected, was seriously considered because it produces spatially balanced samples. A spatially ordered frame in this case meant placing all main stem stretches first in the frame, followed by all stretches in the lowest tributary, followed by all stretches in the second-to-lowest tributary, and so on. However, the primary difficulty with systematic samples is that multiple studies with different sample size requirements cannot utilize a common true grid sample. Using systematic samples, it is also difficult to add stretches to the sample if, for example, crews finished field work earlier than expected. Another disadvantage of systematic sampling, although rarely realized in practice, is that by chance the spacing of the systematic sample could equal the periodicity of a cyclic response. At the workshop, systematic sampling was eventually discarded in favor of GRTS samples (described below) because GRTS samples guarantee spatial balance yet allow multiple studies to maximize overlap of selected streams by utilizing a common sample. GRTS samples also allow units to be added easily after an initial sample has been drawn. Because GRTS samples are not evenly spaced, it is not possible for sample locations to be in phase with a cyclic response.

The only drawback to GRTS samples is they are difficult to understand and to actually draw. At the workshop, Tony Olsen described characteristics of GRTS samples and a copy of his recent paper on the topic was included in workshop materials (Stevens and Olsen, 2004). Briefly, GRTS samples randomly but “hierarchically” order the frame so that stretches with similar river mile coordinates tend to be close to one another in the frame. A systematic sample with random start is then taken from the ordered frame, and the “hierarchical” ordering is reversed to produce an ordered list of sample stretches. The “hierarchical” ordering utilizes the base-2 representation of each stretch’s lower (or middle) coordinate to randomly swap increasingly smaller sections of river. While the details of actually drawing a GRTS sample are best left to Stevens and Olsen (2004), both Tony Olsen and Trent McDonald indicated that they had publicly available software for drawing a proper GRTS sample. At the workshop, it was recommended that a qualified statistician closely supervise selection of the BUFF and OZAR GRTS samples.

The most desirable characteristic of a GRTS sample is that for any sample size, say n , the first n stretches in the ordered GRTS sample constitute a spatially balanced sample of size n . Even if a small number of the first n units are not included in the sample, spatial balance of the GRTS sample will remain high. This characteristic is desirable because it allows multiple studies to co-

locate and add stretches in a way that guarantees spatial balance. For example, assume 10 stretches are to be surveyed by the hellbender study, 2 stretches are to be surveyed by the geomorphology study, and 25 stretches are to be surveyed by the fish study. Under the GRTS design and assuming all three field protocols could be applied to all stretches, the hellbender project would visit the first 10 stretches in the ordered sample. The geomorphology study would visit the first 2 stretches, and the fish project would visit the first 25 stretches in the list. In this way, overlap is maximized because 10 of 25 fish stretches would also be sampled for hellbenders, and 2 of those 10 would also receive geomorphological measurements. Furthermore, the 2 geomorphology, 10 hellbender, and 25 fish stretches would be spatially balanced.

If a study's field protocol could not be applied to a stretch in ordered GRTS sample, that study would discard the stretch and proceed with the next in the list. Continuing the example from the previous paragraph, assume that among the first 10 stretches in the sample were 3 were deemed unsuitable for hellbenders because they were not on main stem rivers. In this case, the hellbender study would skip those stretches and replace them with the 11th, 12th, and 13th stretches in the list assuming they were main stem stretches. Discarding stretches in this way effectively reduces the area to which statistical inferences apply. Given the desire for park-wide estimates expressed at the workshop, such restriction should be kept to a minimum.

Membership Design

Many ecological studies are short-term and specify nothing more than their spatial sampling plan. Monitoring plans, however, are much longer term and therefore must also specify which sample units are to be measured during each sampling occasion (here, sample occasion = field season). That is, long term monitoring plans must also specify a temporal sampling plan. A temporal sampling plan is specified by describing two additional design elements; the membership design and the revisit design (definitions below) (McDonald, 2003). To specify the membership and revisit design, the concept of a *panel* of sample units is needed. A *panel* of sample units is defined to be a set of units that are always all visited during the same occasion. When panels of sample units are constructed, sample effort can be rotated from panel to panel through time, which effectively rotates field effort among sample units and therefore space. Such temporal sampling designs are called *rotating panel designs*. This section describes two membership designs recommended for BUFF and OZAR. One membership design is recommended when one or more study's field seasons do not overlap or do not gain efficiency by co-visitation. The other membership design is recommended when co-visitation by two or more studies is highly efficient logistically. The next section describes the recommended revisit designs.

A *membership design* is defined as the plan by which sample units become members of a particular panel of sample units. For example, a random membership design might specify that members of panels be chosen at random without replacement from the frame. A stratified membership design would specify that all units within a set of mutually exclusive areas be placed in the same panel. A stratified membership design was considered by workshop participants for implementation at BUFF and OZAR because the stratified (or blocked) membership design minimizes distances between sample units visited within a single sample occasion. That is, annual samples of stretches would not be "spread out", but the totality of

stretches visited after a few years would be “spread out”. However, the stratified membership design was rejected because travel costs between sample units in the two parks is not extraordinary, and spatial balance of the annual samples was deemed more important.

To select sample units for most panels in the studies discussed at the design workshop, one of two types of membership designs was recommended depending on the efficiencies gained by co-visitation. The first membership design assures a large degree of co-location across studies, but not necessarily co-visitation. Under membership design 1, and assuming that n_1 sample units are required in panel 1, n_2 sample units are required in panel 2, and so on, the first n_1 sample units in the GRTS sample would be assigned to panel 1, the next n_2 units would be assigned to panel 2, and so on. This assignment causes the sample units in each panel to “interpenetrate” in space due to the spatial balance inherent in the GRTS. An advantage of this membership design is that each panel is guaranteed to be a spatially balanced sample of river stretches drawn from the entire population, and inferences can therefore be made to the entire population using data from every panel. Disadvantages of this membership design include increased travel costs between sample units compared to some alternate plans, and the fact that co-visitation among studies with different sample size requirements is not built into the design.

The second membership design is recommended for two or more studies where co-visitation of sample units is highly efficient logistically. This membership design assures a large degree of co-visitation and co-location, but does not guarantee spatial balance of the total sample from studies with less than the maximum sample size. Under membership design 2, the study with the maximum sample size requirement should be allocated sample units as above. Panel i of other studies with the same revisit schedule, but lower sample size requirements, should be allocated a subset of the sample units allocated to panel i of the first study. This membership plan should become clear in the Co-Location and Co-Visitation section where both the membership and rotation designs are considered together.

Recommendations for membership in panels of all studies discussed at the planning workshop appear in Table 1; however, these recommendations may change when plans for co-visitation are finalized prior to the first field season. With the exception of the hellbender and lead studies, all other study’s membership designs were GRTS samples allocated to panels using membership design 1. Because hellbenders are thought to be extremely rare, restricted to the main stems of rivers in both parks, and a reconnaissance survey is planned, panel 1 of the hellbender study was recommended to consist of just those stretches where hellbenders have been seen in the past. The remaining areas of the main stem rivers would be selected for the hellbender project by allocating the GRTS samples to panels as described above. Designers of the lead study indicated that it was critical to sample a 1.4 km stretch of Blair Creek. Lead levels in that section of Blair Creek are thought to be heavily influenced by an adjacent lead mine outside park boundaries. This Blair Creek stretch will therefore be placed in the lead study’s panel 1. All other waters, including tributaries, will be sampled by the lead study using a GRTS sample and allocation to panels using membership design 1. Several historically sampled macroinvertebrate sample sites exist in both parks. These sites will continue to be sampled when possible, and data from these historical sites will eventually be compared to data collected under this monitoring design.

Revisit Design

Once panels of sample units are defined, it is necessary to define the way sampling effort will rotate among panels through time. In general, power to detect trends in environmental parameters increases as the number of revisits to sample unit increases. Conversely, the precision with which average parameter levels are estimated increases when the number of distinct sample units increase. In certain studies, the best revisit design would specify that members of panel 1 be visited during year 1, members of panel 2 be visited during year 2, and so on. Under this scheme, no sample unit is ever revisited, and precision of average level estimates is maximized but power to detect trend is low. In another study, the best revisit design would dictate that a single panel be visited every year. Under this plan, power to detect trend is high but precision of average level estimates is low. The always-revisit plan also exacts a high response burden on a few units.

The revisit plan recommended for BUFF and OZAR is a compromise between power to detect trend and precision of mean level estimates. The compromise involves allocating some fraction of annual field effort (e.g., 25%, 50%, or 75%) toward re-sampling stretches on a frequent basis. The remainder of annual field effort will be allocated toward re-sampling stretches on a less frequent basis. For example, designers of the macroinvertebrate study recommended that 50% of annual sample size be dedicated to re-visiting stretches in a single panel every year. The remaining 50% of annual sample size would be dedicated to visiting one of 5 additional panels on a 5 year rotating basis. Recommendations for the revisit schedule and effort allocation for studies under consideration for BUFF and OZAR are given in Table 2.

All studies proposed for BUFF and OZAR, except the hellbender, contain 1 panel with annual revisits, and 5 other panels with a 5 year revisit interval. Placing the majority of annual field effort into sampling members of the annual panel will provide more data on trends and annual variability, at the cost of visiting fewer total sites. This would be advantageous if estimation and detection of trend was a paramount objective for the study. If trends are paramount, the generally accepted statistical rule-of-thumb is to allocate $\geq 50\%$ or more to the always revisit panel. Allocating a majority of field effort to the annual panel is also a good idea if the response in question exhibits high annual variability. If, on the other hand, high precision of park-wide estimates is a paramount objective, or annual variability is low, the majority of annual field efforts should be assigned to panels with less-frequent revisit cycles in order to boost the total number of sites visited.

Co-Location and Co-Visitation

Under membership design 1 and the proposed revisit designs, each study will fill the appropriate panels with units starting at the beginning of the list and continuing until all panels are filled (Figure 2). One study, the hellbender, will reject tributary stretches until its panels are filled with main stem stretches. This membership plan will assure spatial balance and a high degree of co-location, but not necessarily a high degree of co-visitation. For example, assume the first unit in the GRTS sample is a tributary stretch, and the second unit is a main stem stretch where no hellbenders have been found previously. The fish + mercury, geomorphology, and macroinvertebrate studies would include the first unit as a member of their respective panel 1. The lead study would include the same unit as a member of their panel 2. The hellbender project

would not include the first GRTS unit because it is not a main stem stretch. The second unit in the GRTS sample would be included in panel 1 of the fish + mercury, geomorphology, and macroinvertebrate studies, and panel 2 of the lead and hellbender studies. Allocation of units to panels for the different studies would continue in this way until each study filled their sample size requirements. Using membership design 1 and assuming different annual sample sizes, some units that are common to multiple studies will be on different revisit schedules. For example, the macroinvertebrate study might visit a particular stretch every year, while the fish study visits the same stretch once every 5 years. Or, the macroinvertebrate study might visit a stretch in 2005, 2010, 2015, etc, while the fish study visits the stretch in 2007, 2012, 2017, etc.

If it is efficient to co-visit 2 or more study's sites, the revisit plans of the studies must be the same (e.g., there is a [1-4] revisit component in 5 of the 6 proposed studies), and membership design 2 can be used. Membership design 2 would achieve a higher degree of co-location, co-visitation, and spatial balance, but could not absolutely guarantee spatial balance of sample sites after one cycle of the revisit design, especially for studies with small sample sizes. Membership design 2 would first identify the study with the most units in a single panel, and allocate units to the panels of this study starting at the beginning of the GRST list, exactly as membership design 1 dictated. Other studies with the same revisit cycle but smaller panel size requirements would fill their panels from units in similarly numbered panels of the first study (Figure 3). For example, suppose the macroinvertebrate study requires 6 units in panels that will be visited on a 5 year rotating basis, and that the geomorphology study requires 5 units in panels visited every 5 years (i.e., panel 2 of both studies). The macroinvertebrate study would fill all its panels starting at the beginning of the GRTS sample, and preserve the ordering of units within each panel. The geomorphology study would then allocate the first 5 units in each of the lead study's panels to their panel on the same rotation schedule. This membership design would be possible only for panels on the same rotation scheme

References

- Stevens, D. L., and A. R. Olsen (2004) "Spatially balanced sampling of natural resources", *Journal of the American Statistical Association*, **99**, p. 262-278.
- McDonald, T. L. (2003) "Environmental Trend Detection: A Review", *Environmental Monitoring and Assessment*, **85**, p. 277-292.

Table 1: Membership designs recommended for monitoring studies proposed on BUFF and OZAR. Each study's annual sample size is assumed = n .

Study	Total Sample Size	Area of Inference	Panel #	# Stretches	Membership Design
Hellbender	$3n-2k$	Known mainstem hellbender stretches	1	k	Mainstem stretches in which > 0 hellbender were found during reconnaissance surveys. Number unknown, assumed = k
			2	$n-k$	First $n-k$ mainstem stretches in GRTS sample that are not known hellbender stretches.
		Unknown mainstem hellbender stretches	3	$n-k$	Second $n-k$ mainstem stretches in GRTS sample that are not known hellbender stretches.
			4	$n-k$	Third $n-k$ mainstem stretches in GRTS sample that are not known hellbender stretches.
Fish + Mercury	$4n$	Stretches fishable by similar gear	1	$0.25n$	First $0.25n$ stretches in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			2	$0.75n$	First $0.75n$ stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			3	$0.75n$	Second $0.75n$ stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
		Stretches fishable by similar gear	4	$0.75n$	Third $0.75n$ stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			5	$0.75n$	Fourth $0.75n$ stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.
			6	$0.75n$	Fifth $0.75n$ stretches after panel 1 in park-wide GRTS sample. Some fished with boat shocker, some with backpack shocker.

Table 1: (Cont'd)

Geomorphology	$4n$	All stretches	1	$0.25n$	First $0.25n$ stretches in park-wide GRTS sample.
		All stretches	2	$0.75n$	First $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			3	$0.75n$	Second $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			4	$0.75n$	Third $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			5	$0.75n$	Fourth $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			6	$0.75n$	Fifth $0.75n$ stretches after panel 1 in park-wide GRTS sample.
Macroinvertebrates	$3n$	All stretches	1	$0.5n$	First $0.25n$ stretches in park-wide GRTS sample.
		All stretches	2	$0.5n$	First $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			3	$0.5n$	Second $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			4	$0.5n$	Third $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			5	$0.5n$	Fourth $0.75n$ stretches after panel 1 in park-wide GRTS sample.
			6	$0.5n$	Fifth $0.75n$ stretches after panel 1 in park-wide GRTS sample.
Lead	$5n-4$	The Blair stretch	1	1	The Blair Creek stretch. This stretch is 1.4km and is potentially influenced by adjacent lead mine
		All stretches minus Blair	2	$n-1$	First $n-1$ stretches in park-wide GRTS sample that are not Blair
			3	$n-1$	Second $n-1$ stretches in park-wide GRTS sample that are not Blair
			4	$n-1$	Third $n-1$ stretches in park-wide GRTS sample that are not Blair
			5	$n-1$	Fourth $n-1$ stretches in park-wide GRTS sample that are not Blair
			6	$n-1$	Fifth $n-1$ stretches in park-wide GRTS sample that are not Blair

Table 2: Revisit plans recommended for monitoring studies proposed on BUFF and OZAR. 'x' in the right-most columns indicates all sample units in that panel are to be visited that year.

Study	Revisit Notation	Panel #	% of Annual Effort	Year											
				1	2	3	4	5	6	7	8	9	10	11	12
Hellbender	[1-0,1-2]	1	Unknown	x	x	x	x	x	x	x	x	x	x	x	x
		2			x		x			x			x		
		3	Unknown		x			x			x			x	
		4				x			x			x			x
Fish + Mercury	[1-0,1-4]	1	25%	x	x	x	x	x	x	x	x	x	x	x	x
		2			x				x					x	
		3				x				x					x
		4	75%			x					x				
		5					x					x			
		6						x					x		
Geomorphology	[1-0,1-4]	1	25%	x	x	x	x	x	x	x	x	x	x	x	x
		2			x				x					x	
		3				x				x					x
		4	75%				x				x				
		5						x				x			
		6							x				x		
Macroinvertebrates	[1-0,1-4]	1	50%	x	x	x	x	x	x	x	x	x	x	x	x
		2			x				x					x	
		3				x				x					x
		4	50%				x				x				
		5						x				x			
		6							x				x		
Lead	[1-0,1-4]	1	1 stretch	x	x	x	x	x	x	x	x	x	x	x	x
		2			x				x					x	
		3				x				x					x
		4	100% - 1 stretch				x				x				
		5						x				x			
		6							x				x		

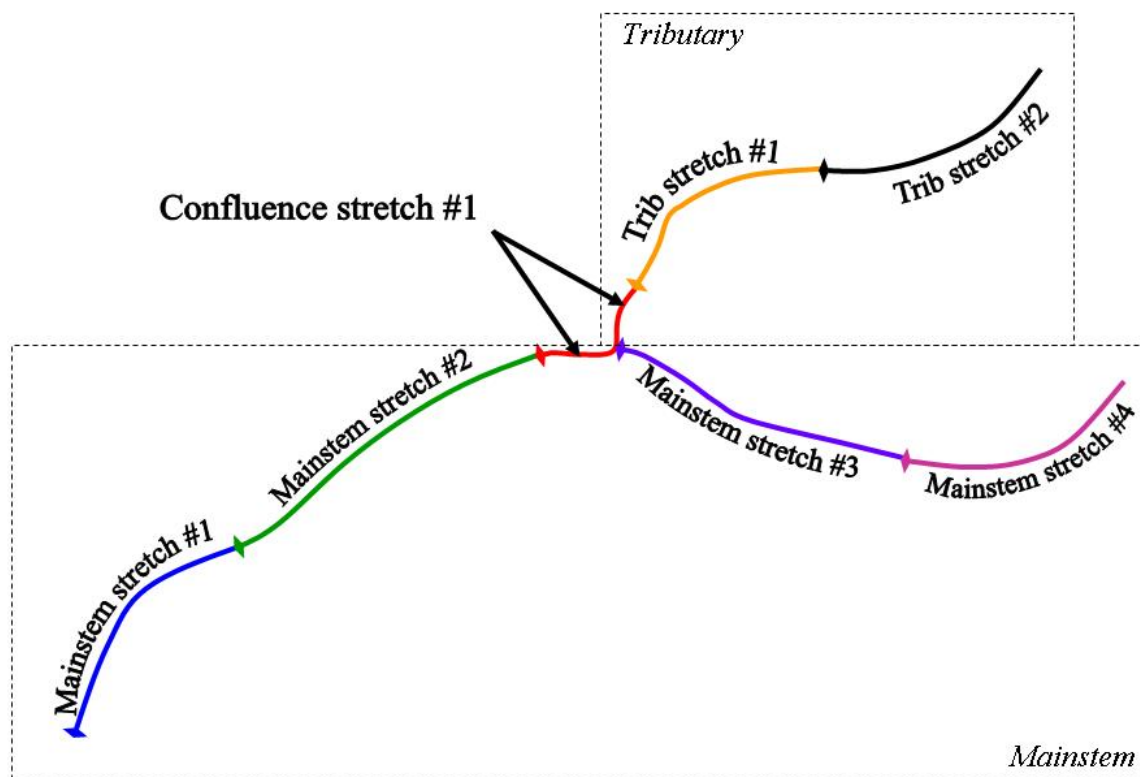


Figure 1: Fictional mainstem and tributary rivers showing boundaries of 4 mainstem stretches, 2 tributary stretches, and 1 confluence stretch. When possible, boundaries of mainstem and tributary stretches are at obvious landscape features such as bridges, access points, cliffs, etc. Confluence stretches run from below the mixing zone on the mainstem to above the backwater zone on the tributary.

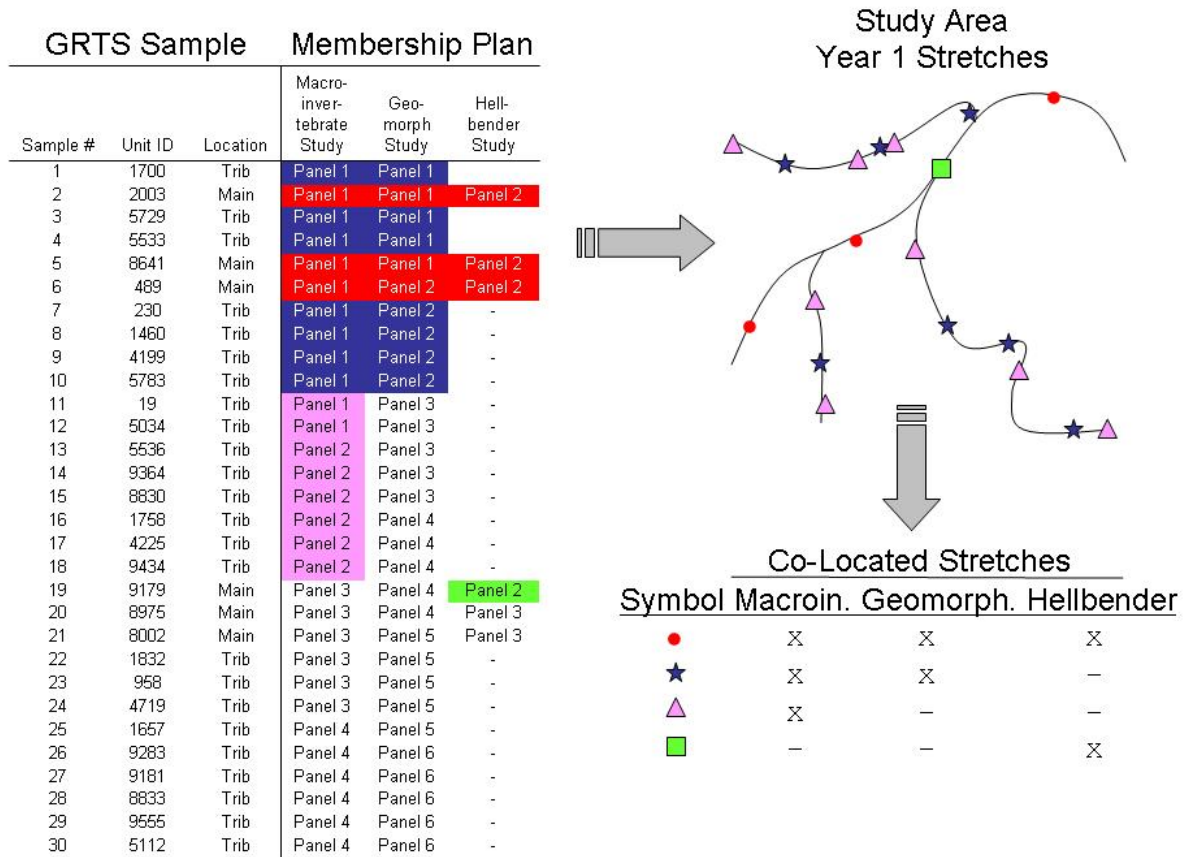


Figure 2: Pictorial representation of the membership plan recommended for BUFF and OZAR yielding high co-location of points across studies, but not necessarily high co-visitation. In the table on the left, a GRTS sample is allocated to panels of the lead, geomorphology (“geomorph”), and hellbender studies. Co-located stretches indicated on the right. Even though stretches are co-located, some are in different panels and receive different visitation schedules. Revisit plans for panels in this example appear in Table 2.

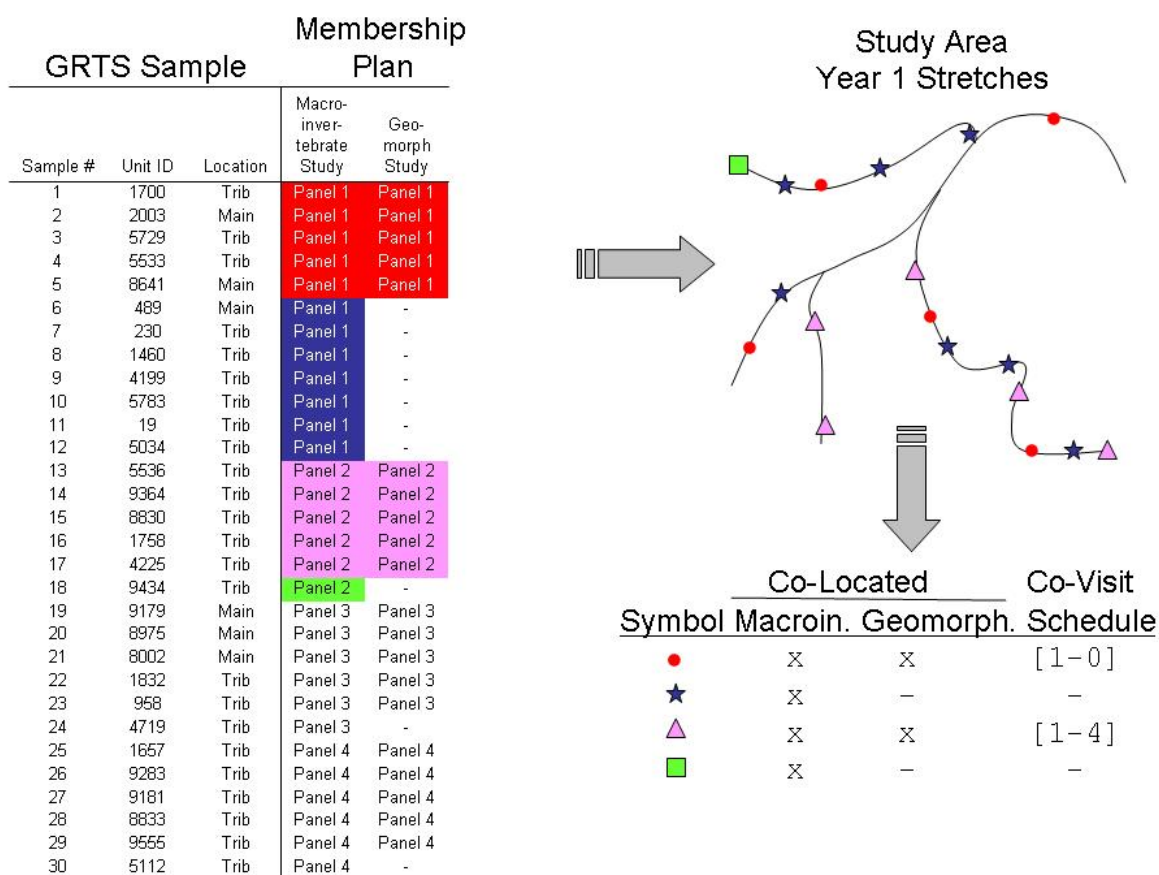


Figure 3: Pictorial representation of an alternate membership plan for studies with common revisit schedules. In the table at right, stretches in the GRTS sample are first allocated to panels of the lead study, which has the maximum panel sizes (annual sample). Stretches are then allocated to the geomorphology (“geomorph”) panels from similar numbered panels in the lead study. For example, stretches in panel 1 of the geomorphology study are a subset of the stretches in panel 1 of the lead study.